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RING ME: Potential radiation levels from beam faults in the AGS ring

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RING ME*

Potential Radiation Levels From Beam Faults in the AGS Ring

Dana Beavis

The AGS ring is examined for the potential to expose on-site personnel to direct radiation from losses inside the AGS ring. Estimations for the attenuation of radiation for various sections of the AGS ring are presented in section I. In section II, a brief discussion on the potential source terms are presented. Finally, in section III, areas which require possible upgrades are discussed.

I. Estimation of Attenuation.

The definition of attenuation used in this report is defined as the reduction of radiation caused by shielding or distance scaled to a distance of 1 meter from the source.

The attenuation of radiation for a shield is estimated using a simple formula:[1]

$$\text{attenuation} = \exp(-d/1)/(r^2)$$

where r is the distance from the source to the observation point, d is the thickness of the shield in gm/cm^2, and 1 in the attenuation length in gm/cm^2 which is set at 110 gm/cm^2 in this report. The attenuation of penetrations (labyrinths) are estimated using the simple labyrinth formula given by Tesch.[2] All attenuations are given in terms of dose at a distance of 1 meter from the source and $1/r^2$ reduction is assumed (a point source).

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* Preferably not around the neck!

Below are presented the estimated attenuations presented by either generic group or by specific location. Attenuation from various items have been ignored which can provide additional reduction in the potential radiation. These items include ring magnet steel (typically 12 inches thick) and cables in pipes.

1. Berm Top.

The thickness of the AGS berm top varies from 10-23 feet. The entire thickness is assumed to be soil with a density of 1.9 gm/cc. Figure I gives the attenuation as a function of soil depth assuming 13 feet from the source to the tunnel roof. Most areas of the ring have been upgraded to a minimum of 17 feet and up to about 23 feet in locations where high losses are expected. Typical attenuation for the berm top is less than 1×10^{-6}. Several remaining thin areas are listed below:

Location	Thickness (feet)	Attenuation
Typical upgrade	18	8×10^{-7}
K-7 escape hatch	13	2×10^{-5}
Booster - AGS	13.5	1×10^{-5}
Linac - AGS	11	6×10^{-5}
C-14 escape hatch	11	6×10^{-5}
Road over berm	10	1×10^{-4}
North conjunction area	10	1×10^{-4}

2. Berm Side.

Typically the soil thickness through the side of the berm is considerably larger than the berm top and is not discussed except for specific locations which are thin and listed separately.

3. Pipes.

The inside of the AGS berm has numerous 2 foot pipes for cable runs into the AGS tunnel. The lengths of these vary from 38 feet to 50 feet. Figure II gives the attenuation as a function of length for these pipes when treated as 2-legged labyrinths. A typical attenuation is 7×10^{-6} (45 feet).

The HITL pipe is 24 inches in diameter, 40 feet long and pitched at 5.3 degrees. Treated as a 2-legged labyrinth it has an attenuation of 1×10^{-5}. It should be noted that the pipe has sand bags packed at each end which give additional attenuation except for the beam line.

The FEB extraction pipes are 12 inches in diameter with lengths of 32 and 38 feet giving an attenuation of 5×10^{-6}.

The L-19 alcove has a 12 inch pipe which has an attenuation of 2×10^{-6}. This pipe has a very high cable density.

There is a series of 8- inch diameter pipes in the north conjunction area which go to the adjacent power supply building, Bldg. 921. These pipes vary in length from 24 to 34 feet. When treated as a 3- legged labyrinth the attenuation is 4×10^{-7}.

There are two 2-foot diameter pipes which enter the ring near H8. These pipes exit on the retaining wall 15 feet above the ground and are 20 feet long. The estimated attenuation is 2×10^{-4}.

Two 2-foot pipes that exit on the outer wall into the northwest building and are 76-feet long. The estimated attenuation is 1×10^{-7}. In addition there are two 10-inch pipes with an attenuation of 10^{-8}.

A summary for pipes penetrating the ring is given below:

Pipe	Attenuation
45-ft. (typical) (2-ft. diameter)	7×10^{-6}
HITL pipe (without sandbags)	1×10^{-5}
FEB extraction pipes	5×10^{-6}
L-19 alcove pipe	2×10^{-6}
8" pipes to Bldg. 921	4×10^{-7}
H8 pipes	2×10^{-4}
Northwest Building (24 inch)	1×10^{-7}

4. Fan Houses.

The supply and return ducts for the fan houses enter the AGS tunnel at the top near the roof. The two ring supply ducts are 16 x 44 inches, while the return duct is 16 x 88 inches. The following has been estimated for the fan houses:

Location	Distance	Small Duct	Large Duct
A House	43 feet	9×10^{-6}	2×10^{-5}
B,C,D Houses	12 feet	5×10^{-4}	1×10^{-3}
E House	34 feet	2×10^{-5}	6×10^{-5}

5. Entrance Labyrinths and Plug Doors.

The AGS ring has a series of entrance labyrinths for personnel access and plug doors for equipment access. Given below are the estimates for these areas.

The south gate labyrinth has 137 feet of distance from the gate to the ring magnets and has 90° of curvature. Treated as a 2-legged labyrinth an attenuation of 1.8×10^{7} is obtained.

Linac to AGS Labyrinth was estimated from the ring to the gate (NZ322). Treated as a 3-legged labyrinth the attenuation from the ring was 2.8×10^{-4}. This is only relevant when the AGS has heavy ion operation.

The north plug door labyrinth was estimated to have an attenuation of 3.5×10^{-6} treated as a 3-legged labyrinth. The north plug door was treated as a shield of heavy concrete 7-feet thick (density of 3.6 gm/cc) and an attenuation of 3.7×10^{-6}. There may exist areas around the edge of the door where less shielding is available.

The south plug door was treated as 4-feet of heavy concrete and an attenuation of 3.3×10^{-5} was obtained. There may exist areas around the edge of the door where there is less effective shielding.

The north conjunction area labyrinth was treated as a 3-legged labyrinth with an attenuation of 3.2×10^{-5}.

The AGS to Booster labyrinth has an attenuation of 6.4 x 10^{-7}. The long wall of the labyrinth probably reduces the effectiveness of the labyrinth as well as a cable run inside the labyrinth and the last segments of the labyrinth are rather short. A cable run inside the labyrinth has an attenuation of 1.4 x 10^{-5}. A trench running from the AGS to the Booster near the labyrinth has an estimated attenuation of 10^{-3}.

The list below summarizes these areas:

Location	Attenuation
South gate labyrinth	2 x 10^{-7}
North gate labyrinth	4 x 10^{-6}
North plug door	4 x 10^{-6}
South plug door	3 x 10^{-5}
North conjunction labyrinth	3 x 10^{-5}
AGS-Booster labyrinth	6 x 10^{-7}
AGS-Booster cable run	1 x 10^{-5}
AGS-Booster trench	1 x 10^{-3}
AGS-Linac NZ22 gate	3 x 10^{-4}

6. Escape Hatches.

The C-14 and K-7 escape hatches have two potential paths for radiation. These areas can be treated as having both direct radiation from a possible loss point in the ring adjacent from the escape shaft and as 2-legged labyrinth for radiation to escape. The direct line of sight from the base of the escape hatch door to the AGS ring has only about 140 gm/cm^2 of shielding. An attenuation of 4.8 x 10^{-3} is obtained primarily from the distance. If treated as a labyrinth an attenuation of roughly 8.4 x 10^{-3} is obtained. The direct radiation to the fence, which is 20 feet from the escape hatch door, has an attenuation of 2.2 x 10^{-8}.

7. Weak Side Wall Shielding.

There are several locations of the AGS tunnel with weak side wall shielding.

The retaining walls on the east and west side of the ring just north of the target building are concrete which is 17 feet thick. The attenuation is 2.5 x 10^{-7}.

The interface between the ring and the northwest building has a varying wall thickness. Sixteen feet along the northwest building has light concrete shielding which is 6 feet thick and stands 13.5 feet tall. The wall behind varies from 4 to 8 feet of concrete. Thus, the thickness varies from about 12.3 feet to 17 feet of soil equivalent. The attenuation for the 12 feet of soil equivalent and 10 feet in the ring tunnel is 4.0×10^{-5}.

Above the shielding blocks there is only the 4 to 8 feet of concrete with the attenuation of 3.0×10^{-3} for the thinnest section. North of the concrete blocks the shield increases from 8 feet to 32 feet thick at the north gate labyrinth. The attenuation for 8 feet of concrete with an additional 10 feet of distance in the ring is 1.9×10^{-4}.

The interface between the AGS target building shield and the tunnel wall has a thin shield at the top of the tunnel at the interface. The shield may be as thin as 1 foot of concrete along the joint and then quickly increases in thickness. For 1 foot of heavy concrete and a distance of 13 feet, an attenuation of 2.0×10^{-2} is obtained. This section only views a potential source in a backwards direction.

The interface between the AGS tunnel and the south end of the target building has several potential weaknesses. The retaining wall on the east side has 12 feet of concrete. The attenuation is 9.6×10^{-6}. A thin spot of approximately 12 feet of concrete between F19 and the west side of the target building exists. The attenuation for this would be 1.6×10^{-5}.

The north wiring tunnel has several weaknesses. There is a direct line of sight from the platform near the trap door to the AGS magnets with at most, 15 inches of concrete. Assuming no concrete, the attenuation from distance is 2.0×10^{-2}. The outside wall of the tunnel varies from about 4 to 7 feet of concrete at the weakest locations. The attenuation for the 7-foot section is estimated to be 1.7×10^{-4}.

The forward end of the FEB tunnel has a wall thickness which is as thin as 7 feet and then increases in thickness. An attenuation of 5×10^{-4} is estimated for the thinnest part.

The target building roof is 8 feet of heavy concrete. The attenuation is 2.6×10^{-5}. The east sidewall shielding is heavy concrete, 10 feet thick, and has an attenuation of 3.5×10^{-6}. A small section at the south end has 8 feet of heavy concrete.

The north conjunction area has a shielding wall which has been constructed with three different thicknesses. The wall is constructed of: 4 feet of heavy concrete with 3 feet of steel, or 8 feet of heavy concrete with 3 feet of steel, or 8 feet of heavy concrete. Taking into account that there is at least 80 feet to the ring, the attenuation is $3.1\ 10^{-9}$, 9.0×10^{-10}, and 5.9×10^{-7}. A trench runs underneath the 8 foot heavy concrete section and when treated as a 3-legged labyrinth, has an attenuation of 5.4×10^{-6}. In addition, the retaining wall to the ring between J-7 to J-10 is thin, about 11 feet at the narrowest section with an attenuation of 7.5×10^{-5}.

A summary is given below of these weak locations and the estimated attenuations.

Location	Attenuation
Retaining wall north of target building.	
East side (17 ft. thick)	2×10^{-7}
West side (17 ft. thick)	2×10^{-7}
Northwest Building	
At concrete blocks	4×10^{-5}
North of concrete blocks	2×10^{-4}
Above concrete blocks	3×10^{-3}
North Target Building Ring Interface	2×10^{-2}
South Target Building Ring Interface	
East retaining wall (12 ft.)	1×10^{-5}
F19 to target building (west)	2×10^{-5}
North Wiring Tunnel	
At entrance hatch	2×10^{-2}
Outside through 7 ft.	2×10^{-4}
Outside through 4 ft.	1×10^{-3}
Front of FEB Tunnel	5×10^{-4}
Target Building	
Concrete roof	3×10^{-5}
Concrete sidewall	4×10^{-6}
North Conjunction Area	
8 ft. heavy concrete	6×10^{-7}
4 ft. heavy concrete and 3 ft. steel	3×10^{-9}
J7 retaining wall	8×10^{-5}
Trench	5×10^{-6}

8. South Wiring Tunnel.

The south wiring tunnel has 3 cable paths which enter the tunnel at a common point. There is one large cable way which leads to a terminal room above the MCR and the Westinghouse building. The distance is 85 feet to the gate and an attenuation of 2.7×10^{-7} is obtained. A smaller cable run goes to the target building and is 25 feet long with an attenuation of 6.2×10^{-5}. Finally, the third cable path goes outside towards the Siemens building. The attenuation of this trench is 3×10^{-5}.

The cable way across the AGS ring has only about 1 foot of concrete separating the AGS tunnel from the cable way floor. The attenuation form the ring to the gates at the Westinghouse and MCR terminal room is 5.1×10^{-6}.

II. Source Estimates.

The proper estimate of the potential source terms requires knowledge of the beam intensity, beam energy, and the geometry of the loss. The most uncertain estimate is the geometry for the full energy beam. It is assumed that the orbit of the 200 MeV injected beam can be sufficiently distorted to cause the beam to interact in any single element about the ring. I will also assume that this is also possible with the future injected Booster beam, although less likely. It is very unlikely that the entire full energy beam can be lost at an arbitrary point. For the present it will be assumed that this can happen. Assuming the entire beam interacts in a thick target, equation 2 of reference 1 has been used to calculate the potential dose equivalent rate at 1 meter for three selected beam energies and associated intensities.

	Linac Injection	Booster Injected	Full Energy Beam
Intensity	4.0×10^{14}/sec	10^{14}/sec	3.0×10^{13}/sec
Energy	200 MeV	1.5 GeV	28.5 GeV
Point Source	2.4×10^{8} mrem/hr	4.5×10^{8} mrem/hr	2.5×10^{9} mrem/hr

It should be kept in mind that these maximum losses may substantially overestimate actual achievable radiation sources. An estimate of the radiation pattern has been made using the program CASIM.[3] A 28 GeV/c beam was forced to interact in a cylinder of iron 125 cm long and 3 cm in radius. The star density is shown in Fig. 3 for a heavy concrete tunnel starting at a radius of two meters. The dose equivalent can be estimated from the star density using a conversion factor which assumes the hadron shower is well developed. This is not the case for the interior of the shield wall and will cause an overestimate of the radiation levels. However, the main purpose is to examine a predicted pattern for a particular source. At 90° from the source the star density corresponds to 2.4 x 10^8 mrem/hr at 1 meter (10^{17} protons/hr) and at 40° to 1.5 x 10^9 mrem/hr. To examine the initial angular dependence of the radiation pattern, CASIM was run with the 28 GeV/c beam forced to interact in the center of a 1 cm sphere of iron. The estimated does equivalent rate at 1 meter per interacting proton is given in Fig. IV as a function of polar angle. The radiation pattern is substantially peaked in the forward direction. To simplify estimates one needs to extract an average expected source for evaluating weak spots.

The potential source term used in section III is 5 x 10^8 mrem/hr. This is based on the following reasoning:

1. The geometry of Fig. III is more realistic than using the angular distribution of Fig. IV and forward angles are usually not accessible except with large distance.

2. Usually there is additional shielding in the forward direction for which credit has not been taken.

3. Full beam loss at a point at 28 GeV/c is the least likely type of beam fault.

The 5 x 10^8 mrem/hr is only a factor of 3 below the 40° number extracted from Fig. III and equals the simple estimate for the full Booster injected beam of 4.5 x 10^8 mrem/hr. When applying such an approximation some judgement should be applied to areas which may not match the assumptions.

Heavy ion operations have less potential for producing radiation. Assuming the projected Si intensity of 7.5 x 10^9/sec at 15 GeV, a maximum point source at one meter is 9.5 x 10^6 mrem/hr, about 50 times less than the injected Booster proton beam.

III. Suggested Upgrade Approach.

The suggested upgrade approach for the AGS ring is based on the following assumed characteristics:

1. That the duration of full beam faults is usually much less than an hour.

2. That faults with durations approaching or exceeding an hour in duration are only a portion of the full beam intensity, such as 10% or less.

3. That the number of faults that occur during the year is reasonably small.

4. That the occupancy around the AGS ring and especially the weak spots is very low.

5. Most weak locations are small in area.

With items 1-5 assumed and understanding the limited resources available, the approach suggested is:

1. Determine reasonable source terms with fault studies.

2. Identify potential weak locations.

3. Add appropriate radiation monitors and barriers where necessary.

Naturally, without item 1 complete it is not possible to recommend final solutions. However, it has been assumed that the solutions proposed and the potential dose estimates are accurate enough to warrant incorporating them before FY92 high intensity operations.

The following table lists the maximum allowed dose equivalent rate and the corresponding attenuation necessary to stay within the guideline assuming 5.0×10^8 mrem/hr for the various types of radiation areas and should be used as a guide for identifying areas needing upgrade:

Area Classification	Maximum Dose Eq. Rate	Attenuation Needed
Uncontrolled	5 mrem/hr	10^{-8}
Radiation Area	100 mrem/hr	2.0×10^{-7}
High Radiation Area	5000 mrem/hr	10^{-5}
Very High Radiation Area	50000 mrem/hr	10^{-4}

It should be noted that we are dealing with fault levels which are many orders of magnitude higher than normal operating levels. In addition, the guidelines typically are for dose in an hour and active devices can be used to decrease the dose in an hour.

Since most of the attenuations do not meet the 10^{-8} criteria, it is obvious that all Uncontrolled Areas should be kept away from weak spots, even the berm top. Two possible solutions are:

1. Encompass the entire AGS berm and its interior in a Radiation Area.

2. Encompass the AGS berm in a Radiation Area but leave sections of the interior as Uncontrolled Areas including the access road over the berm.

Both of these methods would share an outside boundary. The installation of a permanent 5-foot high fence around the outside of the AGS berm was started last year, where the berm upgrade was complete. Thus, the section between Bldg. 911 and the Booster has been completed. It is recommended that the fence be installed between Bldg. 914 and the north conjunction area after the berm upgrade in the area and before FY92 operations. The area near the north conjunction area should be posted as a Radiation Area. Eventually, a permanent fence should enclose the g-2 experimental building, the beam line, and the north conjunction area.

The road over the berm may be difficult to leave as an Uncontrolled Area if the assumed source term is accurate. The estimate is for a potential dose equivalent rate of 50,000 mrem/hr during a maximum fault. Even with an active system, a brief fault lasting a few seconds could potentially exceed the criteria of 20 mrem in an Uncontrolled Area during a fault. A fault study was conducted in this area with full energy beam.[4] Scaling for higher intensity levels of 6000 mrem/hr would be expected. A more detailed analysis of this fault may be able to account for the factor of 8 difference. At a minimum, this area would require an active dual fail safe system, such as two Chipmunks placed in the area.

If sections of the interior area of the berm are left uncontrolled, then an interior fence should be placed sufficiently far from any of the above listed penetrations and weak spots which include fan houses, pipes, F10 house, north wiring tunnel trench, the west retaining wall north of the target building, the north wiring tunnel area, and the trench from the south wiring tunnel, north conjunction area, and the berm top.

The final choice between method 1 and 2 should be chosen this year, and if method 2 is chosen, the interior fence should be installed before FY92 operations of the AGS ring. In addition, the road should be upgraded to an attenuation of 2.0×10^{-7}, with a Chipmunk set to prevent levels above 2 mrem/hr.

The tunnels leading from the terminal room and the Westinghouse building to the gates should be designated as radiation areas. The trench should have an interlocked gate where the covers exist outside. In addition, a radiation detector should probably be added in this area to protect the exit paths from exceeding their limits. This radiation detector would also provide protection for the east retaining wall and the target building, since it would detect faults in this area. Addition of an interlocking Chipmunk would negate the need to designate the entrances as Radiation Areas.

Upgrades for the Berm Top.

Maximum faults could produce levels of 400 mrem/hr on the top of the upgraded berm (18 feet of soil). The distribution of radiation detectors about the AGS ring should prevent this or make it highly or make it highly unlikely. In addition, one might consider adding the internal ring detector, the skinny shield radiation monitors, to the interlock system.

I propose that the berm over the north conjunction area be enclosed in a 7-foot fence and be posted as a High Radiation Area. A Chipmunk in the area (one exists at the labyrinth) would prevent faults above the allowed level.

The Booster-AGS area is already captured in the BTA roof Very High Radiation Area. A Chipmunk external to the shield could protect against high levels and protect the Booster interior from high levels AGS faults.

The Linac-AGS interface is captured in the Booster fence which is a High Radiation Area. A Chipmunk should be placed in this area to prevent large losses. In addition, the Chipmunk would allow for additional protection for the adjacent fan house (C). An alternate site would be to place the Chipmunk near the duct in the fan house.

The locations near K-7 and C-14 escape hatches should have fences expanded to enclose the weak berm location, the fan house exterior, and the escape hatch perimeter. In addition, the Chipmunks should be left in the area to provide protection against elevated levels in the escape hatches, fan houses B and D, and on the weak portion of the berm.

Upgrades for Pipes.

The pipes that exit at the interior of the ring could have levels up to 5000 mrem/hr during a fault. I suggest that with the attenuation ignored for cable and magnets, and the inability to get near the end of the pipe (covers prevent close access) that this radiation level is unrealistically high. In addition, with the increased number (proposed) of distributed radiation detectors around the ring, such faults are likely to be prevented. A fault study should investigate the sensitivity of the detectors to faults in the ring some distance removed from the detector. In addition, one might consider adding the skinny shield monitors to the interlock system.

The HITL pipe is enclosed in an area which is rated a High Radiation Area and is therefore not a problem. In addition, the sandbags were not given credit and the C-14 escape hatch Chipmunk also monitors faults in this area.

The pipes into the Northwest building are behind concrete blocks and fenced off. In addition, the Chipmunk at the north labyrinth gate monitors faults in this area.

The FEB pipes are in an area which is required to be secured by dual interlocks and does not need upgrade.

The 8-inch pipes to Bldg. 921 could fault to 200 mrem/hr. Building 921 is presently a radiation area and should remain so. In addition, the present north conjunction labyrinth gate monitors faults in this area; thus no upgrade should be necessary.

The L-19 pipe is no worse than the associated berm and therefore if distributed Chipmunks provide protection for the berm top, the L-19 alcove pipe is also protected.

The H8 pipes could fault to 100 rem/hr. Shielding should be installed in the pipe to provide at least a factor of 2 attenuation and preferably a factor of 20. The adjacent roof top should be enclosed in a High Radiation Area.

Upgrades for Fan Houses.

The A and E fan houses should be posed as Very High Radiation Areas with no access allowed during beam operation. All fan houses should either have the windows sealed, or a cage put around the windows, or have a fence enclose the sides of the fan house (also the weak spot on the berm and the area around the escape hatch). Padlocks prevented access last year to the fan houses during proton operations. This system should be upgraded. The key for these padlocks could be converted to a captive key in MCR. In addition, fan houses B, C, and D should have microswitches put on the doors. It should be further noted that the Chipmunk in the escape hatches (and proposed at the Linac-AGS interface) monitors levels in adjacent fan house.

I would not propose to move the fan houses unless there is a desire to upgrade the ventilation equipment. In that case a bend should be placed in the duct rather than a straight run.

Upgrades for Labyrinths.

The south gate area is estimated to go to 100 mrem/hr. If one assumes that the Chipmunk at the south plug door and the proposed one in the south wiring tunnel would monitor and prevent faults from elevating levels above the 5 mrem/hr maximum in this area, then no upgrade is necessary.

The south plug door should have the radiation area extend 25 feet out. The present Chipmunk should prevent elevated levels.

The north plug door and labyrinth are fine with the present Chipmunk.

The north conjunction labyrinth needs an adjacent radiation area. The present Chipmunk will prevent elevated levels.

The AGS-Booster interface and labyrinths are fine, provided a Chipmunk on the berm is added (assuming the present one in Bldg. 914 is removed) and that shielding be added to the trench.

Upgrades to Escape Hatches.

A small 2-legged labyrinth should be added to the present face of the escape hatches such that an attenuation of at least 10^{-4} is achieved. The escape doors should be placed at the end of the labyrinth, a fence surrounding the area, and a Chipmunk remain in place. This should be designed this year with completion in the summer 1992 shutdown.

Upgrades for Weak Spots.

The west retaining wall north of the target building should have an adjacent radiation area.

The northwest building needs some shielding added north of the present blocks and above the present height. A Chipmunk should detect faults in this area. The present target building north catwalk Chipmunk does this. If this Chipmunk was moved to the north wiring tunnel, it would also do the job.

The target building tunnel interface should be upgraded with a shield to provide 10^{-4} attenuation if possible and installed before FY92 operations.

The north wiring tunnel should have shielding added to obtain an attenuation of 10^{-4}. In addition, a dual interlock zone should be created around the top wiring tunnel. The Chipmunk on the catwalk should be moved to the north wiring tunnel hatch area. A high radiation area should be defined around this area outside and inside the building. A Radiation Area should encompass this area.

The FEB tunnel has a dual independent system to prevent access to the weak adjacent area of the ring and no upgrade is needed.

Radiation detectors at the north and south wiring tunnels (proposed) should monitor faults and help prevent levels from exceeding the limits for the roof and the sidewalls. If there is concern regarding the sensitivity of these detectors to such faults, then a detector on the concrete roof should be considered.

At the north conjunction area, shielding should be added to the retaining wall from J-7 to J-10. There should be an adjacent radiation area. The shield wall may be one location where the forward radiation potential needs to be considered more carefully.

To summarize the suggested upgrades:

1. Conduct fault studies to better define the source potential for faults and understand the sensitivity of the distributed radiation detectors to arbitrary faults.

2. Decide on whether the road over the berm is worth the effort to leave uncontrolled. If so, begin the engineering for the improvement.

3. Upgrade the monitor system for weak locations.

4. Shield those areas which appear too weak.

5. Define the areas needing upgraded radiation area classification and install barriers as needed.

References

1. K. Tesch, "A Simple Estimation of the Lateral Shielding for Proton Accelerators in the Energy Range 50-1000 MeV," Radiation Protection Dosimetry, Vol. 11, No. 3, pp. 165-172 (1985).

2. K. Tesch, "The Attenuation of the Neutron Dose Equivalent in a Labyrinth Though an Accelerator Shield," Particle Accelerators, Vol. 12, pp. 169-175 (1982).

3. A. Van Ginneken, "CASIM. Program to Simulate Hadronic Cascades in Bulk Matter," FN-272 (1975).

4. J.W. Glenn, "AGS Shield Tests," AGS Studies Report No. 245 (1988).

Figure Captions

1. The attenuation of radiation as a function of depth in the soil shield above the AGS tunnel.

2. Attenuation in a 24-inch pipe as a function of length when treated as a 2-legged labyrinth as discussed in reference (2).

3. Contours of star density distribution predicted by the program CASIM for a 28 GeV/c proton beam forced to interact in an iron target 1 meter long and 7 cm in radius. The surrounding is heavy concrete with a density of 3.6 gm/cc. The star density contours are shown for the radius-beam direction plane.

4. The dose equivalent rates per interacting proton polar angle for a 28 GeV/c beam forced to interact in a 1 cm radius sphere of ion. Levels are given at a distance of 1 meter.

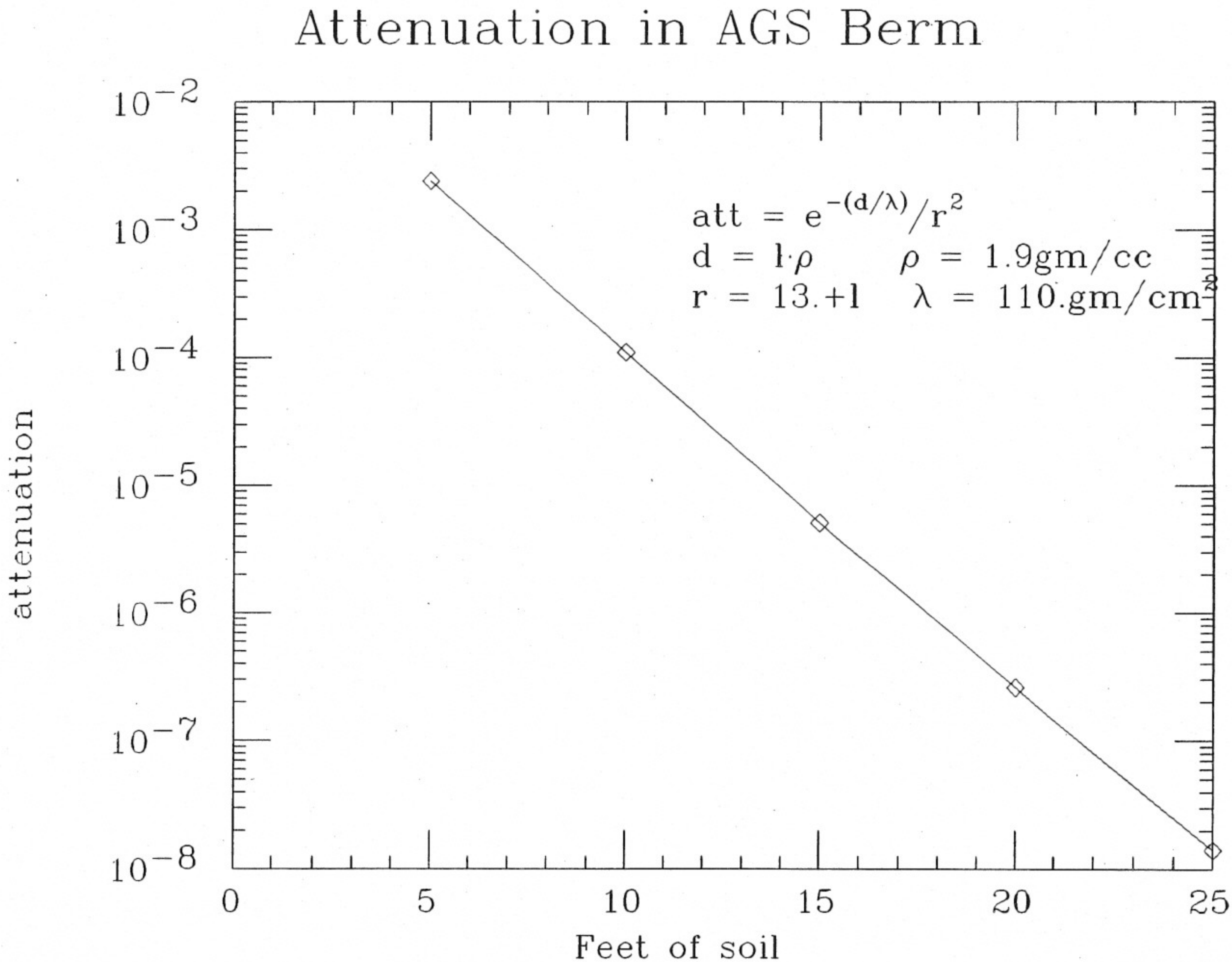

Attenuation in AGS Berm
att = e^{-(d/λ)}/r^2
d = l·ρ   ρ = 1.9gm/cc
r = 13.+l   λ = 110.gm/cm^2
attenuation
Feet of soil
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
5
10
15
20
25

FIG. I

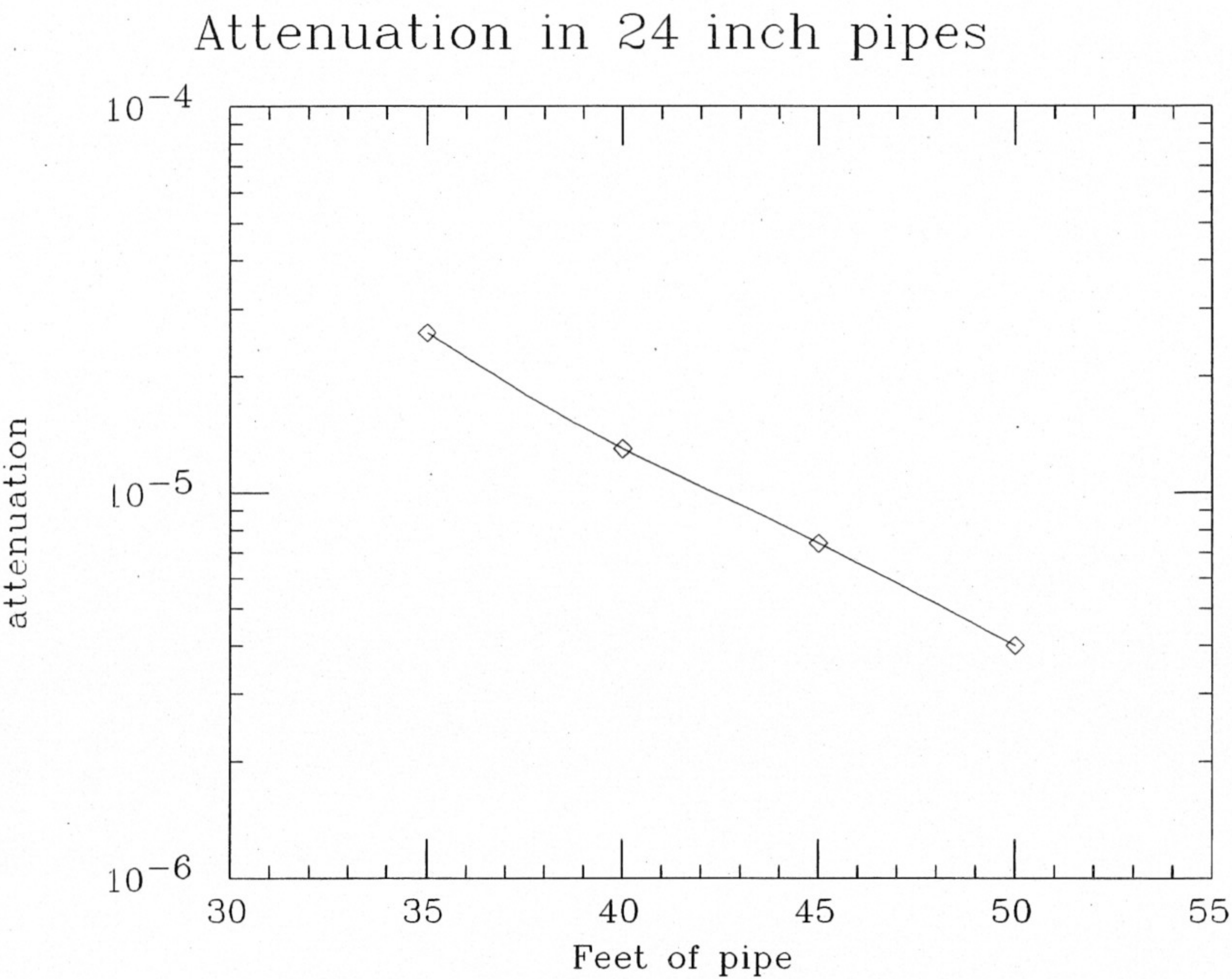
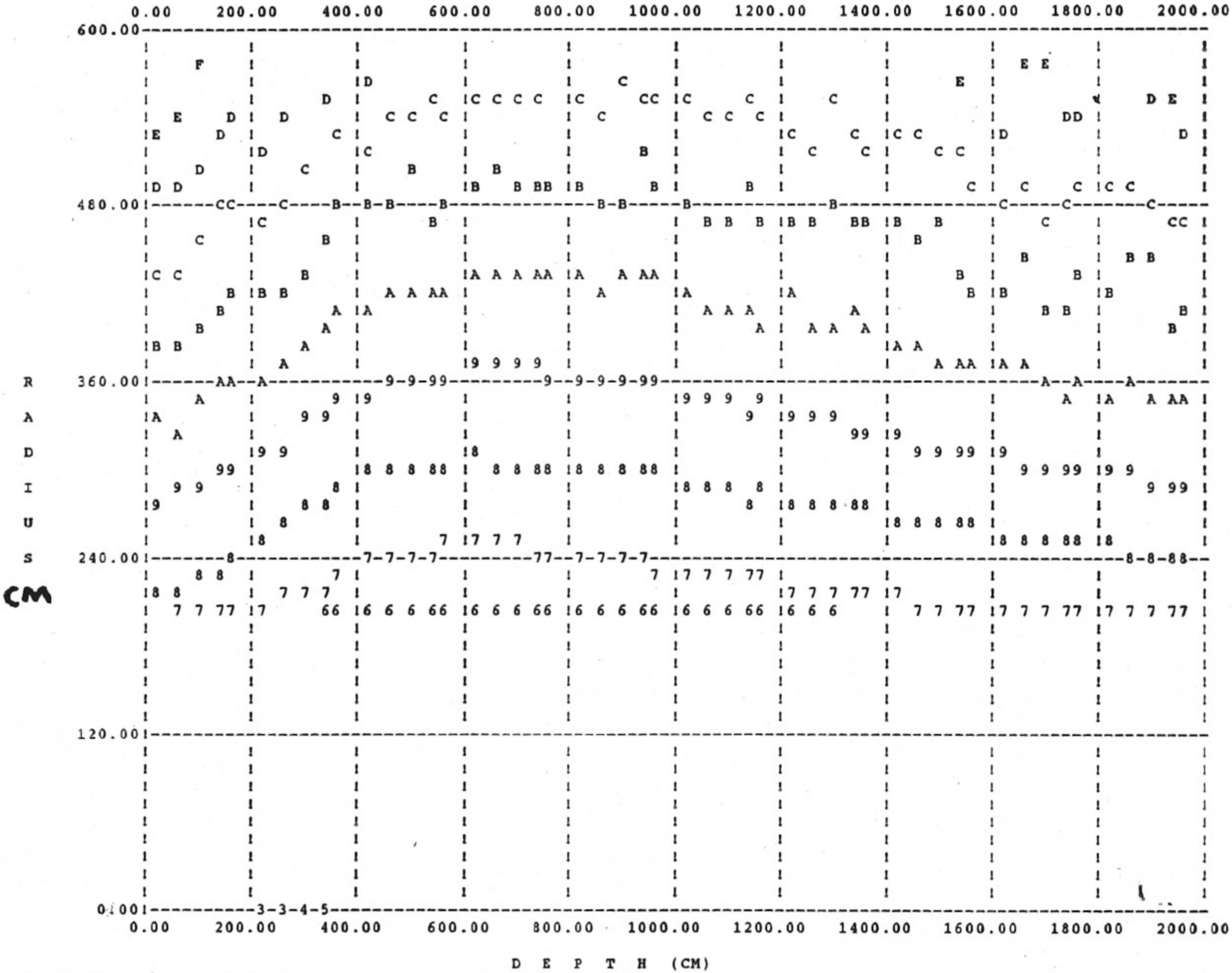

Attenuation in 24 inch pipes
10^{-4}
10^{-5}
10^{-6}
attenuation
30
35
40
45
50
55
Feet of pipe

FIG. II

CONTOURS OF JAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10



R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) :-10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

FORTRAN STOP
BEAVIS job terminated at 24-JUN-1991 18:33:53.90

FIG. 3

Accounting information:

Rad. Dist. for 28 GeV/c Beam

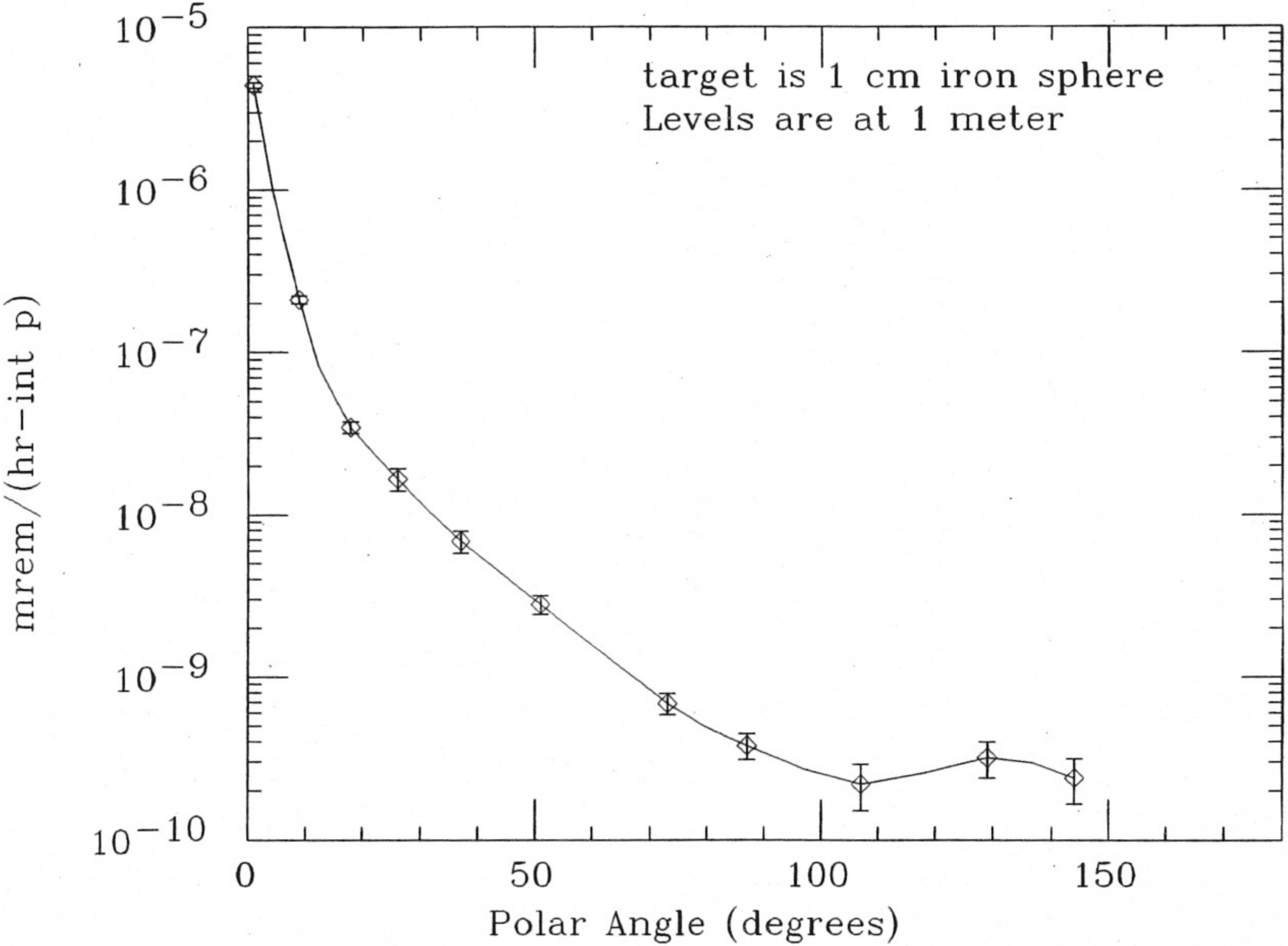


FIG. IV